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PILOT TRACKING PERFORMANCE AS A FUNCTION OF G STRESS AND SEAT BACK ANGLE,

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NOTICES

TECHNICAL REVIEW AND APPROVAL

AMRL TR 76-107

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Robert E. Van Patten

ROBERT E. VAN PATTEN
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The results show degraded weapon tracking at elevated G levels. Improved subject tolerance and greater kill opportunity due to seat back angle are presented at 8G and above. The data were not sufficient to allow modeling of the tracking performance as a function of seat back angle but did show a threshold effect in the 6-8G region on pilot tracking capability.

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PREFACE

The experiment reported herein was conducted by the Aerospace Medical Research Laboratory, Environmental Medicine Division, in 1976, as a study to quantify the effects of present and antecedent G stresses, as well as seat back angle, upon pilot air combat tracking performance. It was conducted under project 7222, task 722210, "Pilot Performance Under Maneuvering G Stress".

The authors acknowledge the valuable efforts of many individuals who contributed to the successful completion of the experiment described in this report: J. Frazier, Dynamic Environment Simulator Supervisor; E. Mersereau, Operation and Maintenance Chief; SMSgt. T. Shriver, NCOIC; V. Skowronski, Subject Training Coordinator; K. Bishop, Software Developer; S. Ward and W. Summers, Data Analysts; Drs. J. Kirkland and J. Kennealy, Medical Monitors; and the volunteer subjects — Capt. A. Banta, Capt. J. Callahan, Lt. R. Johnson, Capt. G. Valentino, and Capt. R. Mattern.

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INTRODUCTION

Since 1935, the results of various research studies (Crosley and Glaister, 1971; Rogers et al, 1973; Burns, 1975) have demonstrated that an aircraft cockpit seat reclined beyond 45° from the vertical increases the maneuvering G accelerations a pilot can tolerate. However, because of aircraft structural and energy limitations, this concept was simply a biotechnology design option and was not explored from the standpoint of operational combat effectiveness or pilot performance.

At present, the F-15/F-16 class of advanced fighter aircraft is straining man's ability to perform multiple high-G maneuver engagements. As a result, interest in an operational test of the reclined cockpit seat has been heightened. In 1974, Air Force Flight Dynamics Laboratory and USAF/Studies and Analysis requested the Aerospace Medical Research Laboratory to pursue the following objectives in a manned simulation program:

- Determine whether the reclined seat concept would allow the pilot to perform minimal aircraft control and combat pursuit functions up to 10 G, and whether such performance would be attainable in an upright seat,

- Evaluate reclined seat performance improvements at G levels less than 10 G, particularly in the 6-8 G region, to quantify the mission effectiveness payoffs to be achieved,

- Assess the sensitivity of performance to changes in seat back angle, thereby providing a basis for engineering design tradeoffs between cost and performance or to select a design point for a flight demonstration,

- Produce a quantitative data base of manned tracking performance under present and antecedent G stresses to be used for predictive computer modelling of air-to-air combat engagements.

The study was to be as realistic as possible, with emphasis on the terminal gunnery tracking portion of an air-to-air engagement.

METHOD

EXPERIMENTAL CONFIGURATION

The Dynamic Environment Simulator (DES), a three degree of motion centrifuge capable of sustained acceleration up to 20 G, was used to perform the study (fig. 1). The cab was configured with a 23-inch video disply, adjustable position reclining seat, and isometric sidearm stick controller. Nonoperative rudder pedals and throttle controls were also included in the cockpit. The cockpit layout is shown in figure 2.

The seat used in the study was a prototype high acceleration cockpit (HAC) seat, built by McDonnell Douglas Aircraft Company under contract with AMRL, and used previously in fixed base reclined seat research simulation. It can be positioned at 20°, 50°, 55°, 60°, or 65° by a motorized system that elevates the seat pan and lower back rest.

Three computers, a PACER 600 hybrid, a PSP 11/40, and a PDP 1, provided the aircraft dynamic responses, trajectory computations, performance scoring and safety monitoring of the DES. A system block diagram is shown in figure 3.

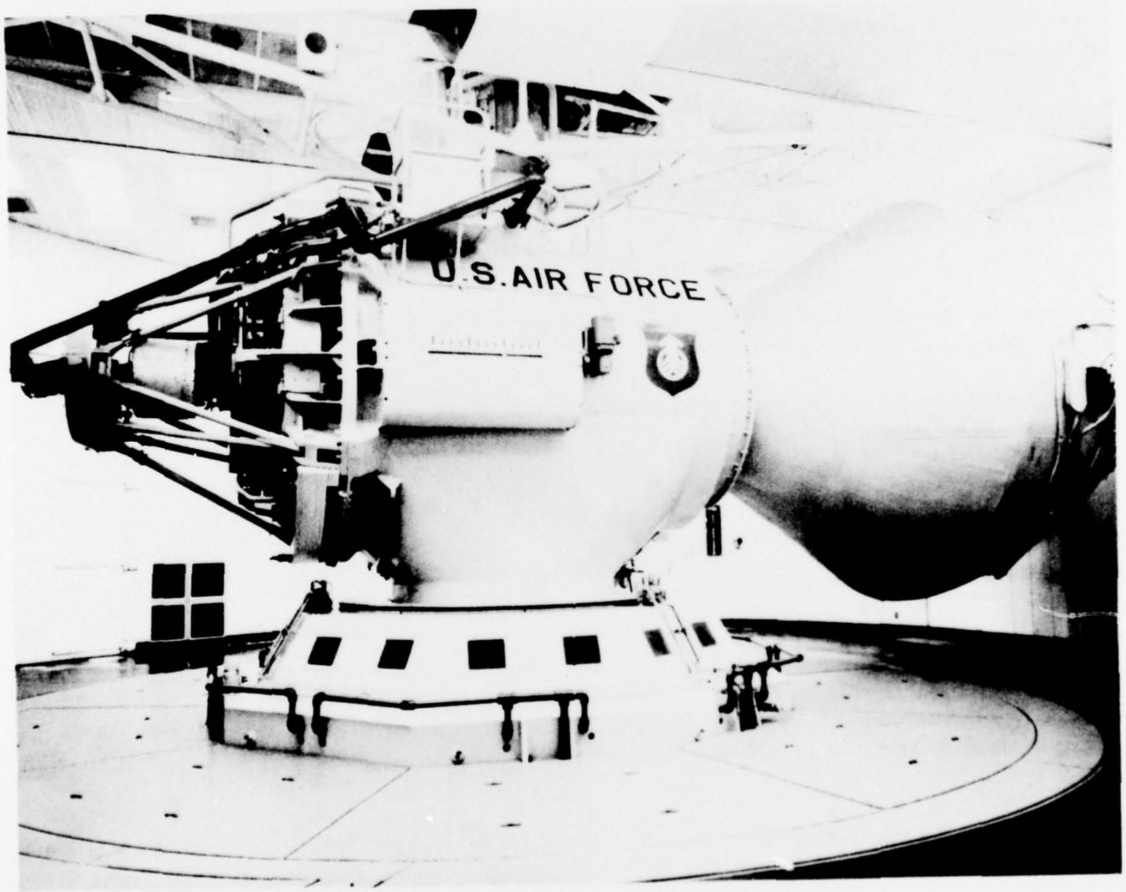

Figure 1. Dynamic Environment Simulator

Figure 2. Cockpit Layout

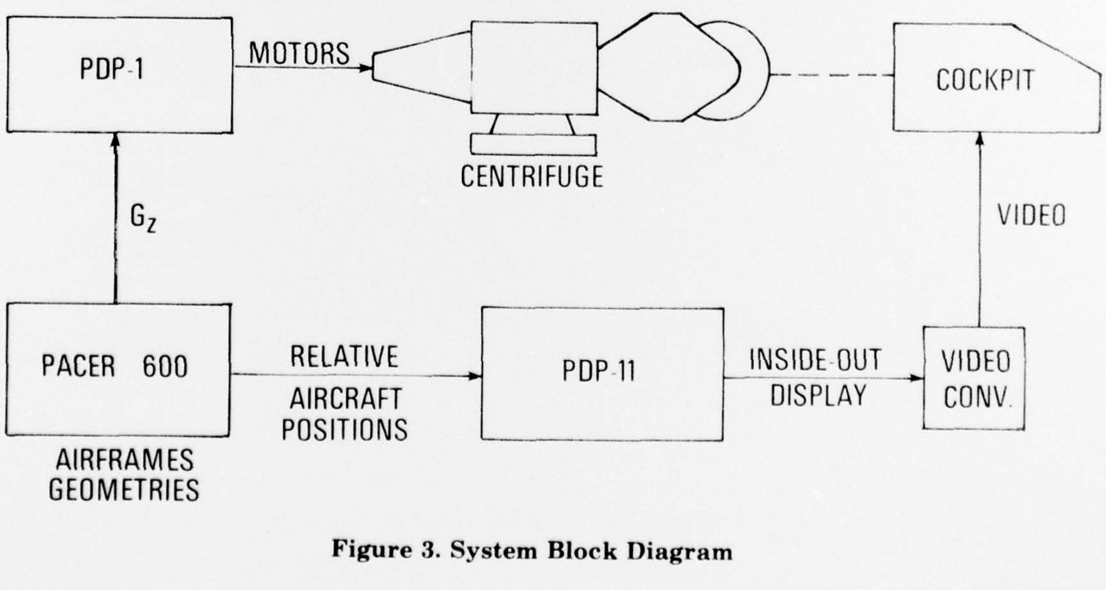

Figure 3. System Block Diagram

The dynamics of the attacker aircraft were representative of an advanced high performance fighter with fly-by-wire controls and sustained turning capability of 10 G. The dynamics were supplied by the Flight Dynamics Laboratory. Five degrees of freedom were simulated and the range to the target aircraft was fixed at 1000 feet. The dynamics of the target aircraft were identical and it was programmed to fly a specified turning trajectory.

The target aircraft was a CRT representation of a three dimensional F-15 class fighter with a 50-foot wingspan. All angles and positions were represented. The gunsight was a simulation of the F-15 sight, except that it was fixed with respect to aircraft fuselage aim with no lead computations. During the runs, the pilot's stick pitch inputs commanded both the vertical display error and the DES G level through the simulated aircraft dynamics.

The subjects' personal equipment during the runs consisted of flight suit, anti-G suit, flight gloves, a cloth harness for emergency egress, and a modified helmet with a laser ear oximeter installed.

The filling pressure schedule in the anti-G suit was the same as reported by Frazier et al., 1975, that is, the pressure was proportional to the upright or Gz component of the total G vector.

EXPERIMENTAL DESIGN

A subject's task during each run was to track the target within the gunsight reticle as close to the center pipper as possible. The target flew a level turning trajectory as shown in figure 4 with peak G levels of 1.6, 6, 8, 9 or 10 G. The seat back angles tested were 20°, 50° and 65°.

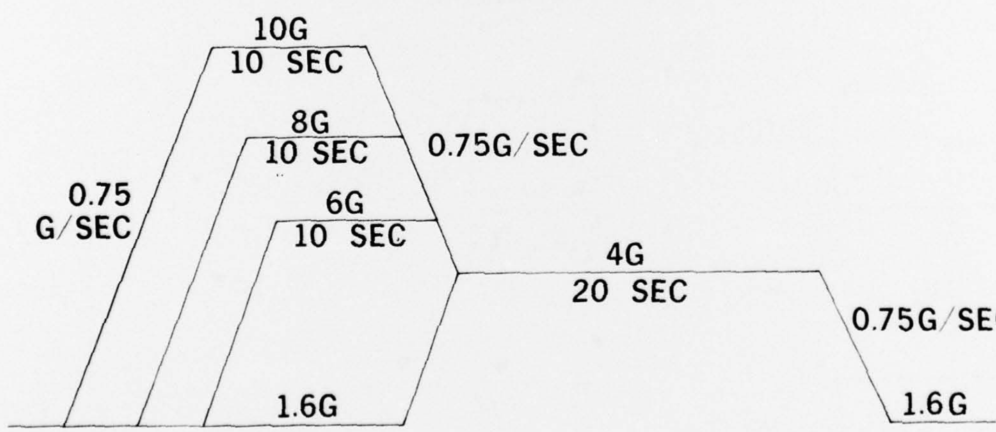

Figure 4. Target G Profile

Each subject's run for one set of exposures included 12 such profiles; one at each combination of seat angle and peak G. However, the maximum peak G for the 20° seat was 9 instead of 10. The limit was directed by the AMRL Human Use Review Committee. After each profile at least one minute was allowed for resting and configuring the seat for the next profile. Since 12 exposures were felt to be excessive for one day the run was split into two days at six exposures each. The order of the 12 exposures was randomized with the condition that not more than two 9- or 10-G exposures, nor more than two 8-G exposures would occur during one day's run for each subject. These conditions were designed to reduce the total fatigue effects. Each set of exposures was replicated twice so that the subjects ran four days in all, two days per replicate set. The primary areas of interest were pilot tracking performances as functions of present G level, antecedent G level, and seat back angle.

SUBJECTS

Five subjects participated in the experiment. These were drawn from the volunteer hazardous duty panel for acceleration stress. All were military personnel; one was a rated USAF pilot.

TRAINING

The subject qualification and training were conducted in three parts. First, a series of G stress indoctrination and medical qualification runs established the fitness of the subjects and acclimatized them to high G stresses up to 10 G. Second, concurrently with the G-stress training, extensive static training developed tracking skills for the data runs. Approximately five weeks of daily half-hour sessions raised the level of tracking performance and allowed it to become asymptotic. Finally, the subjects made three dynamic runs, tracking with the closed loop DES simulating actual data runs.

DATA COLLECTION AND ANALYSIS

Performance data were recorded on digital magnetic tape for postrun analysis. In addition, some real-time reduction was done on the computer for subject feedback scores after each run. For the preexperimental setup and on-line monitoring, a strip chart recorder was also employed.

The run data were recorded at 25 samples/seconds. The following variables were included:

- Vertical aiming error (milliradians)
- Lateral aiming error (milliradians)
- Stick pitch output (lb)
- Roll rate (radians/sec)
- Pitch rate (radians/sec)
- Normal G plant output (ft/sec^2) (DES command)
- Subject's heart rate (beats/min)
- Subject's arterial oxygen saturation (%) (via ear oximeter)
- G-suit pressure (psi)

For purposes of subject feedback, the percentage of time that the target aircraft was within the 50 Mil gunsight reticle was measured and displayed after each exposure. The experimental results were quantified by statistical analyses performed on several variables as functions of G stress and seat back angle. These measurements were separated into performance for the 10-second peak G period, the 20-second 4-G tracking period, and the total time of the exposure:

Percentage time on target

Average RMS error

Number of early terminations

Kills (defined as whether a 1.4-second dwell time on target was achieved or not)

The early terminations were sometimes caused by the inability of the subject to keep the target on the screen at high G and in others by impending blackout. The 1.4-second dwell time for a kill was arrived at on the basis of reviewing extensive gun camera data to determine the average dwell time required for a gun kill. The early terminations and dwell time "kills" were selected because they could be easily related to real world combat performance concepts of either losing the target or killing it.

In addition to the objective performance data, *subjective data were taken on* questionaires the subjects completed after all of their runs were finished. These questionaires were used to supplement the objective results, pinpoint any causes of performance changes, and correlate subject workload with performance. A sample questionaire is shown in the Appendix.

MEDICAL MONITORING

The medical safety monitoring for this experiment consisted of data taken before, during, and after each run. Pre- and postrun data included a 12-lead electrocardiogram, pulmonary function test, and blood samples to determine enzyme levels. A 24-hour postrun blood sample was also taken. During the runs, a qualified medical doctor monitored real-time electrocardiogram displays, cardiotachometer, voice communication, color TV, and arterial oxygen saturation taken from an ear oximeter.

RESULTS

The results of the study will be discussed first in terms of the objective performance measures used. An analysis of variance was performed on each variable with consistent results. In each case the analysis showed significance at the .01 level or better between the performances at the various peak G levels, as well as during the 4-G tracking periods following those peak G exposures. However, only one measure, the number of early run terminations was statistically sensitive to seat back angle. In other words, the seat back angle affected the length of time a subject could track at a given G level, but not necessarily how well he tracked.

The first variable, percent time on target, is presented in table 1; it was calculated over the entire period of each run. Peak and 4-G tracking periods were added together.

TABLE 1
PERCENT TIME ON TARGET

G Level	*Mean*	*Seat Angle*	*Mean*
1.6	93.3	20	52.2
6.0	74.1	50	55.5
8.0	49.5	65	57.0
9.0-10.0	35.4		

The second measured variable was RMS error. This variable was of the greatest interest in aerial combat attrition modelling and was computed separately for the peak G and tracking periods. The mean and standard deviations are given in table 2, with the errors in milliradians. The number of runs completed for each case is also given, out of a total of 10 attempts.

TABLE 2
RMS TRACKING ERROR (MILS)
PEAK G PERIOD

	Seat Angle 20°			Seat Angle 50°			Seat Angle 65°		
Peak G	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n
1.6	24.0	7.0	10	20.5	4.8	10	31.0	12.0	9
6	52.2	17.2	10	68.5	141.1	10	48.9	20.0	10
8	91.4	32.7	10	83.0	29.9	10	96.5	44.9	10
9/10	155.8	102.0	6	117.6	43.4	8	131.7	77.9	7

TRACKING PERIOD (At 4 G)

	Seat Angle 20°			Seat Angle 50°			Seat Angle 65°		
Peak G	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n
1.6	31.2	5.5	10	23.2	6.3	10	31.7	9.4	9
6	45.6	34.8	10	39.1	12.0	10	43.7	24.4	10
8	76.0	50.5	6	90.5	52.0	7	60.0	19.7	10
9/10	-	-	0	104.7	60.1	4	95.6	28.2	4

The third measured variable was whether a run was terminated early, either due to impending blackout or simply losing the target off the edge of the display screen. Since there were no such early terminations in any of the 1.6- or 6.0-G runs, only the 8-, 9-, and 10-G runs were analyzed. Table 3 shows the conditions under which the early terminations occurred. Ten runs were attempted at each combination of seat angle and peak G level. An analysis of variance performed on the 8-, 9-, and 10-G statistics showed that this variable was significant at the .05 level.

TABLE 3
OCCURRENCES OF EARLY TERMINATIONS BY G LEVEL AND SEAT ANGLE*

	G LEVEL				
Seat Angle	1.6	6	8	9/10	Total
20°	-	-	4	10	14
50°	-	-	3	6	9
65°	-	-	-	6	6
Total	-	-	7	22	29

Each cell maximum 10

The final objective variable analyzed was whether the subjects achieved kills as defined by the experiment; that is, whether they achieved during a given exposure a 1.4 second time on target within the 50-mil diameter reticle. Although not statistically significant, the kills achieved for each condition are presented in table 4. They do show interesting trends, particularly at 8 G. These numbers are indicative also of those runs where the enemy might accomplish an escape or conversion, given that he could achieve 10G performance.

TABLE 4
TRIALS WITH 1.4 SECOND KILL OPPORTUNITIES*

Peak G	20°	50°	65°	Total
1.6	10	10	8	28
6	10	10	9	29
8	5	7	10	22
9/10	0	4	2	6
TOTAL	25	31	29	

Each cell maximum 10.

The subjective data were acquired by means of a questionnaire answered by each subject at the completion of his four data runs (see Appendix). In general, their answers agreed with the performance data analyses. The following paragraphs summarize the responses to each question.

- The ***first question*** asked the subjects to rate the quality and quantity of training. All of the subjects considered the training to be satisfactory in these regards, with minor exceptions. Several subjects felt that the number of preparatory physiological qualifying runs was excessive, primarily because of the necessity for taking blood samples each time. Further, they felt that more actual dynamic training runs were needed since they found the transition from static to dynamics tracking to be more difficult than expected.

- ***Question two*** asked each subject to rate his own tracking performance for each set configuration; from 1 (worst) to 7 (best). They rated the 20° seat generally about 4. The 50° and 65° seats were rated about equal at 5. The comments showed that there was some discomfort at the 65° position due to the 45° neck-spine angle. This discomfort was thought to have produced a small performance decrement.

- ***Question three*** asked for a similar rating of workload at each seat angle in the high G runs. The 20° seat was consistently rated highest with an average of 6. The 50° and 65° seats averaged a workload rating of 5. Susceptibility to blackout was given as the reason for the high workload at 20°.

- ***Question four*** asked the subjects to relate any unusual problems, such as discomfort, blackout, disorientation, or making control inputs, that they might have experienced at any of the three seat angles. They responded that the 20° seat position caused some difficulty in maintaining visual aircraft contact, due to partial greyout or spotting of the visual field. The 65° seat position was accompanied by sharp chest pains and breathing difficulties at high G. Blackout was not a major problem at either 50° or 65°; and the overall preference was 50°, with almost no unique problems occurring there.

• ***Question five*** asked for general comments on the study, seat, task or procedures. The responses were varied. One subject wanted more definite feedback immediately following a run on the G conditions just experienced (they were told only if they asked). Several felt that the stick and aircraft dynamics were too sensitive and many stated that more right forearm support was needed. Comments were also made that an image focused at infinity would be more realistic and easier to see than on the TV screen only 30 inches away. One subject felt that the reclined seat would help pilots more who may not have received intensive training at elevated G (up to 10) than ones who fly there regularly; also, that fatigue or repeated sorties might show more pronounced performance differences.

• ***Question six*** asked the subjects to relate the amount of light loss or blackout problems to the combinations of G and seat angle. About half indicated that it was significant above 8 G at all seat back angles, and the other half saw definite differences with light loss becoming a strong factor at 8 G in the 20° seat and minimal or no visual problems in the reclined positions, even at 10 G.

CONCLUSIONS

The conclusions reached by the experimenters after assessing the results of this experiment were the following:

• A reclined seat of at least 50° would allow useful cognitive pilot flight control and tracking functions up to 10 G for 10 seconds, in addition to providing improved blackout tolerance over an upright (20°) seat. Furthermore, such performance was not attainable in the 20° seat, even at 9 G.

• No conclusive statistical evidence could be found to substantiate tracking performance increases, per se, in the 6 to 8 G region, as a result of a reclined seat. The one statistically significant parameter was the number of early terminations, which was significant at G levels 8 and above. On the other hand, trends in the data existed that might indicate the experiment was not sufficently sensitive to detect the small tracking performance differences produced, particularly between 6 and 8 G. However, the experiment was consistently sensitive to differences in performance due to present and antecedent G levels, so the theory that a reclined seat produces performance increases comparable to the reduction in vertical G stress is not valid.

• No operationally important performance improvements were found by increasing the seat angle from 50° to 65°; in fact, subject preferences weighed in favor of the 50° seat with reduced breathing and comfort difficulties. The head restraint might be easily redesigned to reduce the neck angle and improve comfort and performance.

• By all performance measures employed, the experiment showed that each increment in both present and antecedent G stress produced a decrement in tracking performance. These data are given explicitly in the Results Section.

RECOMMENDATIONS

Based on the foregoing conclusions, the following recommendations are presented:

- Further DES studies should be conducted to assess the sensitivity of tracking performance to seat back angle in the narrow 6-9 G range, with special emphasis on peak G durations and repetitions, to uncover cumulative performance or fatigue effects. These studies will explore the sensitivities uncovered in the present experiment and provide a more complete data base on the relationship between performance and G stress.

- That a reclined seat cockpit be implemented in a fighter aircraft test vehicle to validate the results of the centrifuge and fixed base simulator studies. This would provide effectiveness data in a realistic operational flight environment and measure the acceptability of the concept and implementation techniques to the pilot community. Such acceptance has been demonstrated in the DES (Frazier and McElreath, 1976), but not in flight. In addition, the flight test would lend confidence to the data obtained at 9 and 10 G, which is presently attainable only in the centrifuge.

APPENDIX

POSTEXPERIMENT QUESTIONNAIRE

1. Did you consider the amount and quality of training to be:

   Inadequate
   Satisfactory
   Excessive

   Comments:

2. Rate your tracking performance for each seat configuration:

	POOR					GOOD	
20°	1	2	3	4	5	6	7
50°	1	2	3	4	5	6	7
65°	1	2	3	4	5	6	7

Comments:

3. Rate your workload in each seat configuration for the high G runs (6, 8, 9, 10)

	LOW						HIGH
20°	1	2	3	4	5	6	7
50°	1	2	3	4	5	6	7
65°	1	2	3	4	5	6	7

Comments:

4. Did you encounter unique problems (blackout, pain, discomfort, disorientation, control inputs, etc.) at any of the three seat angles?

5. General comments on the study, seat, task, procedures, etc.

6. Was light loss/blackout a significant factor at the following conditions?

	1.6	6G	8G	9/10G
20°				
50°				
65°				

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